

# Appendix J

## Procedure for Determining the Seasonal Energy Efficiencies of Residential Air Distribution Systems

---

This appendix contains a copy of Appendix F from the Residential Alternative Calculation Method (ACM) Approval Manual that describes the procedures for determining the seasonal efficiencies of HVAC air distribution (duct) systems.



# Standard Procedure for Determining the Seasonal Energy Efficiencies of Residential Air Distribution Systems

## 1.0 Introduction

This appendix describes the measurement and calculation methods for determining air distribution system efficiency.

## 2.0 Definitions

**aerosol sealant closure system:** A method of sealing leaks by blowing aerosolized sealant particles into the duct system and which must include minute-by-minute documentation of the sealing process.

**floor area :** The floor area of enclosed conditioned space on all floors of a building, as measured at the floor level of the exterior surfaces enclosing the conditioned space.

**delivery effectiveness :** The ratio of the thermal energy delivered to the conditioned space and the thermal energy entering the distribution system at the equipment heat exchanger.

**distribution system efficiency :** The ratio of the thermal energy consumed by the equipment with the distribution system to the energy consumed if the distribution system had no losses or impact on the equipment or building loads.

**equipment efficiency :** The ratio between the thermal energy entering the distribution system at the equipment heat exchanger and the energy being consumed by the equipment.

**equipment factor :**  $F_{\text{equip}}$  is the ratio of the equipment efficiency including the effects of the distribution system to the equipment efficiency of the equipment in isolation.

**fan flowmeter device:** A device used to measure air flow rates under a range of test pressure differences.

**flowhood:** A device used to capture and measure the airflow at a register.

**load factor :**  $F_{\text{load}}$  is the ratio of the building energy load without including distribution effects to the load including distribution system effects.

**pressure pan :** a device used to seal individual forced air system registers and to measure the static pressure from the register.

**radiant barrier :** a surface of low emissivity (less than 0.05) placed inside an attic or roof space to reduce radiant heat transfer.

**recovery factor :**  $F_{\text{recov}}$  is the fraction of energy lost from the distribution system that enters the conditioned space.

**thermal regain:** The fraction of delivery system losses that are returned to the building.



### 3.0 Nomenclature

$a_r$  = duct leakage factor (1-return leakage) for return ducts  
 $a_s$  = duct leakage factor (1-supply leakage) for supply ducts  
 $A_{\text{floor}}$  = conditioned floor area of building ,  $\text{ft}^2$   
 $A_{r,\text{out}}$  = surface area of return duct outside conditioned space ,  $\text{ft}^2$   
 $A_{r,\text{attic}}$  = return duct area in attic ,  $\text{ft}^2$   
 $A_{r,\text{base}}$  = return duct area in basement ,  $\text{ft}^2$   
 $A_{r,\text{crawl}}$  = return duct area in crawlspace,  $\text{ft}^2$   
 $A_{r,\text{gar}}$  = return duct area inside garage,  $\text{ft}^2$   
 $A_{s,\text{out}}$  = surface area of supply duct outside conditioned space,  $\text{ft}^2$   
 $A_{s,\text{attic}}$  = supply duct area in attic ,  $\text{ft}^2$   
 $A_{s,\text{base}}$  = supply duct area in basement ,  $\text{ft}^2$   
 $A_{s,\text{crawl}}$  = supply duct area in crawlspace,  $\text{ft}^2$   
 $A_{s,\text{gar}}$  = supply duct area inside garage,  $\text{ft}^2$   
 $A_{s,\text{in}}$  = supply duct area inside conditioned space,  $\text{ft}^2$   
 $B_r$  = conduction fraction for return  
 $B_s$  = conduction fraction for supply  
 $DE$  = delivery effectiveness  
 $DE_{\text{design}}$  = design delivery effectiveness  
 $DE_{\text{seasonal}}$  = seasonal delivery effectiveness  
 $E_{\text{equip}}$  = rate of energy exchanged between equipment and delivery system, Btu/hour  
 $F_{\text{cycloss}}$  = cyclic loss factor  
 $F_{\text{equip}}$  = load factor for equipment  
 $F_{\text{flow}}$  = load factor for fan flow effect on equipment efficiency  
 $F_{\text{leak}}$  = fraction of system fan flow that leaks out of supply or return ducts  
 $F_{\text{load}}$  = load factor for delivery system  
 $F_{\text{recov}}$  = thermal loss recovery factor  
 $F_{\text{regain}}$  = thermal regain factor

$K_r$  = return duct surface area coefficient  
 $K_s$  = supply duct surface area coefficient  
 $N_{\text{story}}$  = number of stories of the building  
 $P_{\text{sp}}$  = pressure difference between supply plenum and conditioned space [Pa]  
 $P_{\text{test}}$  = test pressure for duct leakage [Pa]  
 $Q_e$  = Flow through air handler fan at operating conditions, cfm  
 $Q_{\text{total},25}$  = total duct leakage at 25 Pascal, cfm  
 $R_r$  = thermal resistance of return duct,  $\text{h ft}^2/\text{Btu}$   
 $R_s$  = thermal resistance of supply duct,  $\text{h ft}^2/\text{Btu}$   
 $T_{\text{amb},r}$  = ambient temperature for return , F  
 $T_{\text{amb},s}$  = ambient temperature for supply , F  
 $T_{\text{attic}}$  = attic air temperature , F  
 $T_{\text{base}}$  - return duct temperature in basement, F  
 $T_{\text{crawl}}$  - return duct temperature in crawlspace, F  
 $T_{\text{design}}$  = outdoor air design temperature , F  
 $T_{\text{ground}}$  = ground temperature , F  
 $T_{\text{gar}}$  = temperature of garage air , F  
 $T_{\text{in}}$  = temperature of indoor air , F  
 $T_{\text{rp}}$  = return plenum air temperature , F  
 $T_{\text{seasonal}}$  = outdoor air seasonal temperature, F  
 $T_{\text{sp}}$  = supply plenum air temperature , F  
 $\Delta T_e$  = temperature rise across heat exchanger , F  
 $\Delta T_r$  = temperature difference between indoors and the ambient for the return , F  
 $\Delta T_s$  = temperature difference between indoors and the ambient for the supply,  
 $\eta_{\text{ist,seasonal}}$  = seasonal distribution system efficiency

## **4.0 Air Distribution Diagnostic Measurement and Default Assumptions**

### **4.1 Instrumentation Specifications**

The instrumentation for the air distribution diagnostic measurements shall conform to the following specifications:

#### **4.1.1 Pressure Measurements**

All pressure measurements shall be measured with measurement systems (i.e. sensor plus data acquisition system) having an accuracy of  $\pm 0.2$  Pa. All pressure measurements within the duct system shall be made with static pressure probes.

#### **4.1.2 Fan Flow Measurements**

All measurements of distribution fan flows shall be made with measurement systems (i.e. sensor plus data acquisition system) having an accuracy of  $\pm 5\%$  reading or  $\pm 5$  cfm whichever is greater.

#### **4.1.3 Duct Leakage Measurements**

The measurement of air flows during duct leakage testing shall have an accuracy of  $\pm 3\%$  of measured flow using digital gauges.

All instrumentation used for fan flow and duct leakage diagnostic measurements shall be calibrated according to the manufacturer's calibration procedure to conform to the above accuracy requirement. All testers performing diagnostic tests shall obtain evidence from the manufacturer that the equipment meets the accuracy specifications. The evidence shall include equipment model, serial number, the name and signature of the person of the test laboratory verifying the accuracy, and the instrument accuracy. All diagnostic testing equipment is subject to re-calibration when the period of the manufacturer's guaranteed accuracy expires.

### **4.2 Apparatus**

#### **4.2.1 System Fan Flows**

HVAC system fan flow shall be measured using one of the following methods.

##### **4.2.1.1 Plenum pressure matching measurement**

The apparatus for measuring the system fan flow shall consist of a duct pressurization and flow measurement device (subsequently referred to as a fan flowmeter [see section 4.3.7.2.2.]) meeting the specifications in 4.1.3, a static pressure transducer meeting the specifications in Section 4.1.1, and an air barrier between the return duct system and the air handler inlet. The measuring device shall be attached at the air handler blower compartment door. All registers shall be in their normal operating condition. The static pressure probe shall be fixed to the supply plenum so that it is not moved during this test.

##### **4.2.1.2 Flow hood measurement**

A flow hood meeting the specifications in section 4.1.2. can be used to verify the fan flow at the return register(s) after the completion of a rough-in duct leakage measurement. All registers shall be in their normal operating position. Measurement(s) shall be taken at the return grill(s).

### **4.2.2 Duct Leakage**

The apparatus for fan pressurization duct leakage measurements shall consist of a duct pressurization and flow measurement device meeting the specifications in Section 4.1.3.

## **4.3 Procedure**

The following sections identify input values for building and HVAC system (including ducts) using either default or diagnostic information.

### **4.3.1 Building Information**

The calculation procedure for determining air distribution efficiencies requires the following building information:

1. climate zone for the building,
2. conditioned floor area,
3. number of stories,
4. supply duct location and
5. floor type.

#### **4.3.1.1 Default Input**

Using default values rather than diagnostic procedures produce relatively low air distribution-system efficiencies. Default values shall be obtained from following sections:

1. the location of the duct system in Section 4.3.4,
2. the surface area and insulation level of the ducts in Sections 4.3.3, 4.3.4 and 4.3.6,
3. the system fan flow in Section 4.3.7, and
4. the leakage of the duct system in Section 4.3.8.

### **4.3.2 Diagnostic Input**

Diagnostic inputs are used for the calculation of improved duct efficiency. The diagnostics include observation of various duct characteristics and measurement of duct leakage and system fan flows as described in Sections 4.3.5 through 4.3.8. These observations and measurements replace those assumed as default values.

The diagnostic procedures include

- measure supply duct surface area as described in Section 4.3.3.2.
- measure total duct system leakage as described in Section 4.3.8.
- measure system fan flow or observe the presence of a thermostatic expansion valve for claiming ACCA manual D design credit as described in Section 4.3.7.
- Observe the insulation level for the supply ( $R_s$ ) and return ( $R_r$ ) ducts outside the conditioned space as described in Section 4.3.6.
- Observe the presence of radiant barriers.

### 4.3.3 Duct Surface Area

The supply-side and return-side duct surface areas shall be calculated separately. If the supply or return duct is located in more than one zone, the area of that duct in each zone shall be calculated separately. The duct surface area shall be determined using the following methods.

#### 4.3.3.1 Default Duct Surface Area

##### 4.3.3.1.1 Duct Surface Area for More Than 12 feet of Duct Outside Conditioned Space

The default duct surface area for supply and return shall be calculated as follows:

For supplies:

$$A_{s,\text{total}} = 0.27A_{\text{floor}} \quad (4.1) \quad 1$$

For returns:

$$A_{r,\text{total}} = K_r A_{\text{floor}} \quad (4.2)$$

Where  $K_r$  (return duct surface area coefficient) shall be 0.05 for one story building and 0.1 for two or more stories.

##### 4.3.3.1.1 Duct Surface Area for Less Than 12 feet of Duct Outside Conditioned Space

For HVAC systems with air handlers located outside the conditioned space but with less than 12 feet of duct located outside the conditioned space including air handler and plenum, the duct surface area outside the conditioned space shall be calculated as follows:

$$A_{s,\text{out}} = 0.027 A_{\text{floor}} \quad (4.3)$$

Where  $A_{s,\text{out}}$  is substituted for  $A_{s,\text{attic}}$ ;  $A_{s,\text{crawl}}$ ; or  $A_{s,\text{base}}$  depending on the location of the ducts.

#### 4.3.3.2 Diagnostic Duct Surface Area

A well designed duct system can reduce the length of the supply duct. Smaller duct surface area will result in reduced duct conduction losses. Duct surface area shall be calculated from measured duct lengths and nominal outside diameters (for round ducts) or outside perimeters (for rectangular ducts) of each duct run in the building. Improved conduction losses can be claimed for reduced supply duct surface area only (it does not apply to the return duct). Supply plenum surface area shall be included in the supply duct surface area. Diagnostic duct surface area requires measuring duct surface areas separately for each location outside conditioned space ( $A_{s,\text{attic}}$ ;  $A_{s,\text{crawl}}$ ; or  $A_{s,\text{base}}$ ) and the system fan flow to ensure that there is sufficient air flow to deliver the designed heating and cooling loads.

### 4.3.4 Duct Location

Duct location determines the external temperature for duct conduction losses, the temperature for return leaks, and the thermal regain of duct losses. Default duct surface areas by locations of the supply duct shall be obtained from Table 4.1. The default duct surface area for crawlspace and basement applies only to buildings with all supply ducts installed in the crawlspace or basement. If the supply duct is installed in locations other than crawlspace or basement, the default supply duct location shall be "Other".

If ducts are installed in multiple locations, air distribution efficiency shall be calculated for each duct location. Total air distribution efficiency for the house shall be the weighted average based on the floor area served by each duct system.



<b>Table 4.1 Default Assumptions for Duct Locations</b>				
Supply or Return Duct Location	<b>Supply Duct Surface Area</b>		<b>Return Duct Surface Area</b>	
	One story	Two or more story	One story	Two or more story
Attic	100% attic	65% attic 35% conditioned space	100% attic	100% attic
Crawlspace	100% crawlspace	65% crawlspace 35% conditioned space	100% attic	100% attic
Basement	100% Basement	65% basement 35% conditioned space	100% Basement	100% Basement
Other	100% attic	65% attic 35% conditioned space	100% attic	100% attic

#### **4.3.5 Climate and Duct Ambient Conditions for Ducts Outside Conditioned Space**

Duct ambient temperature for both heating and cooling at different duct locations shall be obtained from Table 4.2. Indoor dry-bulb ( $T_{in}$ ) temperature for cooling is 78°F. The indoor dry-bulb temperature for heating is 70°F. Reduction of attic temperature and the reduction in solar radiation effect due to radiant barriers shall only be applied to cooling calculations. The procedures for the installation of radiant barriers shall be as described in ACM Section 4.23. Attic temperatures for houses with radiant barriers shall be obtained from Table 4.2.

**Table 4.2 Default Assumptions for Duct Ambient Temperature**

Climate zone	Duct Ambient Temperature for Heating, T <sub>heat,amb</sub>			Duct Ambient Temperature for Cooling, T <sub>cool,amb</sub>				
	Attic	Crawlspace	Basement	Attic	Attic w/ radiant barrier (supply)	Attic w/ radiant barrier (return)	Crawlspace	Basement
1	52.0	52.2	48.9	60.0	65.4	61.2	54.0	49.1
2	48.0	48.7	56.5	87.0	84.3	84.2	78.0	64.5
3	55.0	54.9	58.3	80.0	79.4	78.2	71.8	62.8
4	53.0	53.1	56.6	79.0	78.7	77.4	70.9	61.4
5	49.0	49.6	52.3	74.0	75.2	73.1	66.4	56.8
6	57.0	56.7	59.9	81.0	80.1	79.1	72.7	64.1
7	62.0	61.1	60.4	74.0	75.2	73.1	66.4	61.6
8	58.0	57.6	60.1	80.0	79.4	78.2	71.8	63.9
9	53.0	53.1	59.6	87.0	84.3	84.2	78.0	66.4
10	53.0	53.1	61.1	91.0	87.1	87.6	81.6	68.9
11	48.0	48.7	59.5	95.0	89.9	91.0	85.1	69.5
12	50.0	50.4	59.3	91.0	87.1	87.6	81.6	67.8
13	48.0	48.7	58.4	92.0	87.8	88.4	82.4	67.6
14	39.0	40.7	55.4	99.0	92.7	94.4	88.7	68.6
15	50.0	50.4	63.4	102.	94.8	96.9	91.3	74.6
16	32.0	34.4	43.9	80.0	79.4	78.2	71.8	54.1

### 4.3.6 Duct Wall Thermal Resistance

#### 4.3.6.1 Default Duct Insulation R value

Default duct wall thermal resistance is R4.2. An air film resistance of 0.7 [h ft<sup>2</sup> °F/BTU] shall be added to the duct insulation R value to account for external and internal film resistance.

#### 4.3.6.2 Diagnostic Duct Wall Thermal Resistance

Duct wall thermal resistance shall be determined from the manufacturer's specification observed during diagnostic inspection. If ducts with multiple R values are installed, the lowest duct R value shall be used. If a duct with a higher R value than 4.2 is installed, the R-value shall be clearly stated on the building plan and a visual inspection of the ducts must be performed to verify the insulation values. In case the space on top of the duct boot is limited and can not be inspected, the insulation R value within two feet of the boot to which the duct is connected may be excluded from the determination of the overall system R value.

### 4.3.7 System Fan Flow

#### 4.3.7.1 Default Fan Flow

The default cooling fan flow with an air conditioner and for heating with a heat pump for **climate zones 8 through 15** shall be calculated as follows:

$$Q_e = 0.70 A_{\text{floor}} \quad (4.4)$$

The default cooling fan flow with an air conditioner and for heating with a heat pump for **climate zones 1 through 7 and 16** and default heating fan flow for forced air furnaces for all climate zones shall be calculated as follows:

$$Q_e = 0.50 A_{\text{floor}} \quad (4.5)$$

#### 4.3.7.2 Diagnostic Fan Flow

To obtain duct efficiency credit for duct systems designed according to ACCA Manual D, a diagnostic fan flow measurement must be performed or the installation of a thermostatic expansion valve must be verified. The access panel on the cooling coil shall be removable for the verification of a thermostatic expansion valve. For ACCA Manual D designed duct system, engineering calculations and the building plan for duct sizing and layout shall also be prepared. The diagnostic fan flow shall be measured using one of the following methods:

##### 4.3.7.2.1 Diagnostic Fan Flow Using Flow Hood:

To measure the system return fan flow, all registers shall be fully open, and the air filter shall be installed. Turn on the system fan and measure the fan flow at the return grille(s) with a calibrated flow hood to determine the total system return fan flow. The system fan flow ( $Q_e$ ) shall be the sum of the measured return flows.

##### 4.3.7.2.2 Diagnostic Fan Flow Using Plenum Pressure Matching:

The fan flow measurement shall be performed using the following procedures:

1. With the system fan on ( in heating mode with burners on for heating, or in cooling mode with compressor on), measure the pressure difference (in pascal) between the supply plenum and the conditioned space ( $\Delta P_{sp}$ ).  $P_{sp}$  is the target pressure to be maintained during the fan flow tests. If there is no access to the supply plenum, then place the pressure probe in the nearest supply duct. Adjust the probe to achieve the highest pressure and then firmly attach the probe (e.g., with duct tape) to ensure that it does not move during the fan flow test.
2. Block the return duct from the plenum upstream of the air handler fan and the fan flowmeter. Filters are often located in an ideal location for this blockage.
3. Attach the fan flowmeter device to the duct system at the air handler. For many air handlers, there will be a removable section that allows access to the fan that is suitable for this purpose. Assure that there is no significant leakage between the fan flowmeter and the system fan.
4. If the fan flowmeter is connected to the air handler outside the conditioned space, then the door or access panel between the conditioned space and the air handler location shall be opened.
5. Turn on the system fan and the fan flowmeter, adjust the fan flowmeter until the pressure between supply plenum and conditioned space matches  $P_{sp}$ .
6. Record the flow through the flowmeter ( $Q_e$ , cfm) - this is the diagnostic fan flow.

In some systems, typical system fan and fan flowmeter combinations may not be able to produce enough flow to reach  $P_{sp}$ . In this case record the maximum flow ( $Q_{max}$ , cfm) and pressure ( $P_{max}$ ) between the supply plenum and the conditioned space. The following equation shall be used to correct measured system flow and pressure ( $Q_{max}$  and  $P_{max}$ ) to operating condition ( $Q_e$ ) at operating pressure ( $P_{sp}$ ).

$$Q_e = Q_{max} \left( \frac{P_{sp}}{P_{max}} \right)^{\frac{1}{2}} \quad (4.6)$$

### 4.3.8 Duct Leakage

#### 4.3.8.1 Duct Leakage Factor for Delivery Effectiveness Calculations

Default duct leakage factors shall be obtained from Table 4.3, using the “not Tested” values.

Duct leakage factors shown in Table 4.3 shall be used in calculations of delivery effectiveness.

Table 4.3 Duct Leakage Factors		
	Duct Leakage Diagnostic Test Performed using Section 4.3.8.2 Procedures	$a_s = a_r =$
Duct systems in homes built prior to April 1, 1999	Not tested	0.86
Duct systems in homes built on or after April 1, 1999	Not tested	0.89
Duct systems in homes of all ages, System with refrigerant based cooling, tested after house and HVAC system completion	( $Q_{25}$ ) Total leakage is less than $0.06 Q_{cool}$	0.96
Duct systems in homes of all ages, System without refrigerant based cooling, tested after house and HVAC system completion	( $Q_{25}$ ) Total leakage is less than $0.06 Q_{heat}$	0.96
Duct systems with refrigerant based cooling, in homes built on or after April 1, 1999, System tested with air handler installed, but prior to installation of the interior finishing wall	( $Q_{25}$ ) Total leakage is less than $0.06 Q_{cool}$ and final duct integrity verified	0.96
Duct systems without refrigerant based cooling, in homes built on or after April 1, 1999, System tested with air handler installed, but prior to installation of the interior finishing wall	( $Q_{25}$ ) Total leakage is less than $0.06 Q_{heat}$ and final duct integrity verified	0.96
Duct systems with refrigerant based cooling, in homes built on or after April 1, 1999, System tested without air handler installed, but prior to installation of the interior finishing wall	( $Q_{25}$ ) Total leakage is less than $0.04 Q_{cool}$ and final duct integrity verified	0.96
Duct systems without refrigerant based cooling, in homes built on or after April 1, 1999, System tested without air handler installed, but prior to installation of the interior finishing wall	( $Q_{25}$ ) Total leakage is less than $0.04 Q_{heat}$ and final duct integrity verified	0.96

#### 4.3.8.2 Diagnostic Duct Leakage

Diagnostic duct leakage measurement is used to quantify total leakage for the calculation of air distribution efficiency. To obtain the improved duct efficiency for sealing the duct system, a diagnostic leakage test as described in section 4.3.8.2.1 or 4.3.8.2.2 must be performed. Houses built on or after

4/1/1999 shall not be allowed to claim duct leakage credit and diagnostic testing may not be done on any HVAC system that uses building cavities such as plenums or a platform return.

#### **4.3.8.2.1 Diagnostic Duct Leakage from Fan Pressurization of Ducts**

The total duct leakage shall be determined by pressurizing the ducts to 25 Pascals. The following procedure shall be used for the fan pressurization tests:

1. Seal all the supply and return registers, except for one return register or the system fan access.
2. Attach the fan flowmeter device to the duct system at the unsealed register or access door.
3. Install a static pressure probe at a supply.
4. Adjust the fan flowmeter to produce a 25 Pascal (0.1 in water) pressure difference between the supply duct and the outside or the building space with the entry door open to the outside.
5. Record the flow through the flowmeter ( $Q_{\text{total},25}$ ) - this is the total duct leakage flow at 25 Pascals.

When the diagnostic leakage test is performed and the measured total duct leakage is less than 6% of the total fan flow, the duct leakage factor shall be 0.96 as shown in Table 4.3.

#### **4.3.8.2.2 Diagnostic Duct Leakage at Rough-in Construction Stage Using An Aerosol Sealant Closure System**

Duct leakage in new construction may be determined by using diagnostic measurements at the rough-in building construction stage prior to installation of the interior finishing wall when using an aerosol sealant closure system. When using this measurement technique, additional verification (as described in section 4.3.8.2.2.3) of duct integrity shall be completed after the finishing wall has been installed. In addition, after the finishing wall is installed, spaces between the register boots and the wallboard shall be sealed. Cloth backed rubber adhesive duct tapes shall not be used to seal the space between the register boot and the wall board.

The duct leakage measurement at rough-in construction stage shall be performed using a fan pressurization device. The duct leakage shall be determined by pressurizing both the supply and return ducts to 25 Pa. The procedures in Sections 4.3.8.2.2.1 and 4.3.8.2.2.2 shall be used for measuring duct leakage before the interior finishing wall is installed.

##### **4.3.8.2.2.1 For ducts with the air handling unit installed and connected:**

###### **For total leakage:**

1. Verify that supply and return plenums and all the connectors, transition pieces and duct boots have been installed. If a platform is used as part of the air distribution system, it must contain a duct, and all return connectors and transition parts shall be installed and sealed. The platform, duct and connectors shall be included in the total leakage test.
2. Seal all the supply duct boots and return boxes except for one return duct box.
3. Attach the fan flowmeter device at the unsealed duct box.
4. Insert a static pressure probe at one of the sealed supply duct boots.
5. Adjust the fan flowmeter to maintain 25 Pa(0.1 in water)between the duct system and outside or the building space with the entry door open to the outside.
6. Record the air flow through the flowmeter ( $Q_{\text{total},25}$ ) - This is the total duct leakage at 25 Pa at rough-in stage.
7. Divide the measured total leakage by the total fan flow calculated from equation 4.4 or 4.5.

If the total leakage is less than 6% of the total fan flow, the duct leakage factor shall be 0.96 as shown in Table 4.3.

#### **4.3.8.2.2.2 For ducts with air handling unit not yet installed:**

##### **For total leakage:**

1. Verify that all the connectors, transition pieces and duct boots have been installed. If a platform is used as part of the air distribution system, it must contain a duct, and all return connectors and transition parts shall be installed and sealed. The platform, duct and connectors shall be included in the total leakage test.
2. Use a duct connector to connect supply and/or return duct box to the fan flowmeter. Supply and return leaks may be tested separately. If there is only one return register, the supply and return leaks shall be tested at the same time.
3. Seal all the supply duct boots and/or return boxes except for one supply or return duct box.
4. Attach the fan flowmeter device at the unsealed duct box.
5. Insert a static pressure probe at one of the sealed supply duct boots.
6. Adjust the fan flowmeter to maintain 25 Pa (0.1 in water) between the building conditioned space and the duct system.
7. Record the air flow through the flowmeter ( $Q_{\text{total},25}$ ) - This is the total duct leakage at 25 Pa.
8. Divide the measured total leakage by the total fan flow calculated from equation 4.4 or 4.5. If the total leakage is less than 4% of the total fan flow, the total duct leakage factor shall be 0.96 as shown in Table 4.3.

#### **4.3.8.2.2.3 Post rough-in duct leakage verification**

After installing the interior finishing wall and verifying that one of the above rough-in tests was completed, one of the following post rough-in verification tests shall be performed to ensure that there is no major leakage in the duct system.

##### **4.3.8.2.2.3.1 Visual inspection**

Remove at least one supply and one return register to verify that the spaces between the register boot and the interior finishing wall are properly sealed. In addition, if the house rough-in duct leakage test was conducted without an air handler installed, inspect the connection points between the air handler and the supply and return plenums to verify that the connection points are properly sealed. All joints shall be inspected to ensure that no cloth backed rubber adhesive duct tape is used unless such tape is used in combination with mastic and drawbands.

##### **4.3.8.2.2.3.2 Pressure pan test**

With register dampers fully open, the house is pressurized to 25 pascals by a blower door, ( If two registers are within 5 feet of each other and are connected to the same duct run, one register shall be sealed off before the pressure pan test is performed). the pressure difference across each register shall not exceed 1.5 Pa.

##### **4.3.8.2.2.3.3 House Pressure Test**

The pressure difference between the building conditioned space and a vented attic shall be measured to determine whether the house pressure is changed appreciably by the operation of the air handler. To perform this test, the pressure difference ( $P_{\text{house}} - P_{\text{out}}$ ) between the building conditioned space and a vented attic (or outside if impossible to access the attic), shall be measured four times:

1. with the fan off ( $\Delta P_{\text{off1}}$ )
2. with the fan on ( $\Delta P_{\text{on}}$ )
3. with the fan on and the return grille 80% blocked ( $\Delta P_{\text{RB}}$ ). Block 80% on all return grilles if the house has two or more returns.
4. with the fan off ( $\Delta P_{\text{off2}}$ )

For each of these measurements, the five-second average pressure shall be measured 10 times and these 10 measurements shall be averaged.

For the house to pass this test, the following conditions must be true:

1.  $\Delta P_{on} - (\Delta P_{off2} + \Delta P_{off1})/2$  must be between +0.8 Pa and -0.8 Pa and
2.  $\Delta P_{RB} - \Delta P_{on}$  must be less than 0.8 Pa.

In addition, the absolute value of  $(\Delta P_{off2} - \Delta P_{off1})$  must be less than 0.25 Pa, or else the test must be repeated. If the repeated test does not meet the above specified values, visual inspection or the pressure pan test or the fan pressurization test must be used. If these tests fail, the duct system needs to be properly sealed and re-verified by a fan pressurization test.

## 4.4 Delivery Effectiveness (DE) Calculations

Seasonal delivery effectiveness shall be calculated using the seasonal design temperatures from Tables 4.2.

### 4.4.1 Calculation of Duct Zone Temperatures

The temperatures of the duct zones outside the conditioned space are determined in Section 4.3.5 for seasonal conditions for both heating and cooling. If the ducts are not all in the same location, the duct ambient temperature for use in the delivery effectiveness and distribution system efficiency calculations shall be determined using an area weighted average of the duct zone temperatures:

$$T_{amb,s} = \frac{(A_{s,attic} + 0.001)T_{attic} + A_{s,crawl}T_{crawl} + A_{s,base}T_{base}}{A_{s,out} + 0.001} \quad (4.7)$$

$$T_{amb,r} = \frac{A_{r,attic}T_{attic} + A_{r,crawl}T_{crawl} + A_{r,base}T_{base}}{A_{r,out}} \quad (4.8)$$

The return ambient temperature,  $T_{amb,r}$ , shall be limited as follows:

For heating, the maximum  $T_{amb,r}$  is  $T_{in,heat}$ . For cooling, the minimum  $T_{amb,r}$  is  $T_{in,cool}$ .

### 4.4.2 Seasonal Delivery Effectiveness (DE)

The supply and return conduction fractions,  $B_s$  and  $B_r$ , shall be calculated as follows:

$$B_s = \exp\left(\frac{-A_{s,out}}{1.08 Q_e R_s}\right) \quad (4.9)$$

$$B_r = \exp\left(\frac{-A_{r,out}}{1.08 Q_e R_r}\right) \quad (4.10)$$

The temperature difference across the heat exchanger in the following equation is used:

for heating:

$$\Delta T_e = 55 \quad (4.11)$$

for cooling:

$$\Delta T_e = -20 \quad (4.12)$$

The temperature difference between the building conditioned space and the ambient temperature surrounding the supply,  $\Delta T_s$ , and return,  $\Delta T_r$ , shall be calculated using the indoor and the duct ambient temperatures.

$$\Delta T_s = T_{in} - T_{amb,s} \quad (4.13)$$

$$\Delta T_r = T_{in} - T_{amb,r} \quad (4.14)$$

The seasonal delivery effectiveness for heating systems shall be calculated using:

$$DE_{seasonal} = a_s B_s - a_s B_s (1 - B_{radr}) \frac{\Delta T_r}{\Delta T_e} - a_s (1 - B_s) \frac{\Delta T_s}{\Delta T_e} \quad (4.15)$$

## 4.5 Seasonal Distribution System Efficiency

Seasonal distribution system efficiency shall be calculated using delivery effectiveness, equipment, load, and recovery factors calculated for seasonal conditions.

### 4.5.1 Equipment Efficiency Factor ( $F_{equip}$ )

Equipment efficiency factor accounts for interactions between the duct system and the operation of the heating or cooling equipment. If the duct size and layout are designed and installed according to ACCA manual D and if the fan flow measurement meets the design specifications, the efficiency factor for cooling for  $F_{equip}$  is 1. Otherwise  $F_{equip}$  for cooling shall be 0.925. For heating,  $F_{equip}$  is 1.

### 4.5.2 Thermal Regain ( $F_{regain}$ )

The reduction in building load due to regain of duct losses shall be calculated using the thermal regain factor. The default thermal regain factors are provided in Table 4.4.



Table 4.4 Thermal Regain Factors	
Supply Duct Location	Thermal Regain Factor [ $F_{\text{regain}}$ ]
Attic	0.10
Crawlspace	0.12
Basement	0.30
Other	0.10

### 4.5.3 Recovery Factor ( $F_{\text{recov}}$ )

The recovery factor,  $F_{\text{recov}}$ , is calculated based on the thermal regain factor,  $F_{\text{regain}}$ , and the duct losses without return leakage.

$$F_{\text{recov}} = 1 + F_{\text{regain}} \left( \frac{1 - a_s B_s + a_s B_s (1 - B_r) \frac{\Delta T_r}{\Delta T_e} + a_s (1 - B_s) \frac{\Delta T_s}{\Delta T_e}}{DE_{\text{seasonal}}} \right) \quad (4.16)$$

### 4.5.4 Seasonal Distribution System Efficiency

The seasonal distribution system efficiency shall be calculated using the seasonal delivery effectiveness from section 4.4.2, the equipment efficiency factor from section 4.5.1, and the thermal recovery factor from Section 4.5.3. Note that  $DE_{\text{seasonal}}$ ,  $F_{\text{equip}}$ ,  $F_{\text{recov}}$  must be calculated separately for cooling and heating conditions. Distribution system efficiency shall be determined using the following equation:

$$h_{\text{dist,seasonal}} = DE_{\text{seasonal}} \times F_{\text{equip}} \times F_{\text{load}} \times F_{\text{recov}} \quad (4.17)$$

where 0.98 accounts for the energy losses from heating and cooling the duct thermal mass.